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Behavior of Tunnel in Layered Soils Under Earthquake Loadings

A Thesis Submitted to the Council of College of Engineering University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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CHAPTER ONE

INTRODUCTION

1.1 General

Tunnels usually are structures passing underground. The first tunnel under the Euphrates, with a length of 900 m, was established in Babylon between 2180 and 2160 BC. Since then, waterways and people around the world have been excavated with simple tools **(Susa, 1986)**.

The tunnels constitute an important underground infrastructure, vital to urban transport and logistics, and thus to the economy of major urban agglomerations. In many cases, they are built-in high seismic areas, so their seismic design can be of prime importance. Determining their seismic response is challenging due to the large number of parameters that influence behavior, including those associated with non-linear soil response, soil-structure interface behavior, and nonlinear structural response. In general, its seismic performance is better than the above-ground structures because the effects of inertia are not important, where the main source of loading is kinetic and stems from the dynamic response of the surrounding soil, which can be carried efficiently by the tunnel as pressure vessels.

The tunnels consider a major significant way of transmission underground. It is beneficial in the construction region where no more roofs can be created to confirm the huge traffic infrastructure. Second, it also provides a fast, continuous flow between the points. So, largely populated cities are presently designing around the world to supply metro lines by means of a system called an underground tunnel system. Though it has numerous useful goals, it has also at the same interval subject to so much damage if it is located in an earthquake-prone zone (**Ahsan et al, 2019**).

Recently researchers concentrate on the seismic behavior of the tunnels in various kinds of soil. **(Wang, 1993; Penzien, 2000; and Bobet, 2010)** advanced closed-form option of solutions to assess the seismically moments and forces in different tunnels resulting the types of failure like racking and ovaling.

The depth of digging for the tunnel beneath the ground, the sort of soil that surrounds all sides of the tunnel, extreme ground acceleration, the strength of the earthquake, and the distance of the tunnel to the earthquake epicenter represent the factors that affect the tunnels under dynamic loading. Many researchers have attituded the experimental and numerical studies on various sides of seismic action of underground infrastructures, by considering the significance of the object. Several numerical studies, like as **(Hashash et al, 2005; Huo et al, 2005; Anastasopoulos et al, 2007; Anastasopoulos et al, 2008; Amorosi and Boldini, 2009; Kontoe et al, 2011; Kontoe et al, 2014; Baziar et al, 2014 and Bilotta et al, 2014)** to research the action of underground infrastructures beneath dynamic loading.

From **Lin Li et al, (2020)**, Wenchuan earthquake that occurred in China in 2008, many tunnels damaged hardly. Longxi Tunnel on Dujiangyan-Wenchuan highway in Figure (1.1) consider an indicative seismic damaged tunnel. The tunnel's fundamentally involvement three kinds of damage: (1) Longitudinal lining crack, (2) Inclined lining crack, and (3) Local lining failure. The lining cracks regarding 2-3 mm wide, distributed around the fault. Figure (1.1 a) shows the local failure that occurred on the tunnel vaults and spandrels. Furthermore, lining disturbance was also noted because of the huge shear force resulting from faulting Figure (1.1 b).

(a)

(b)

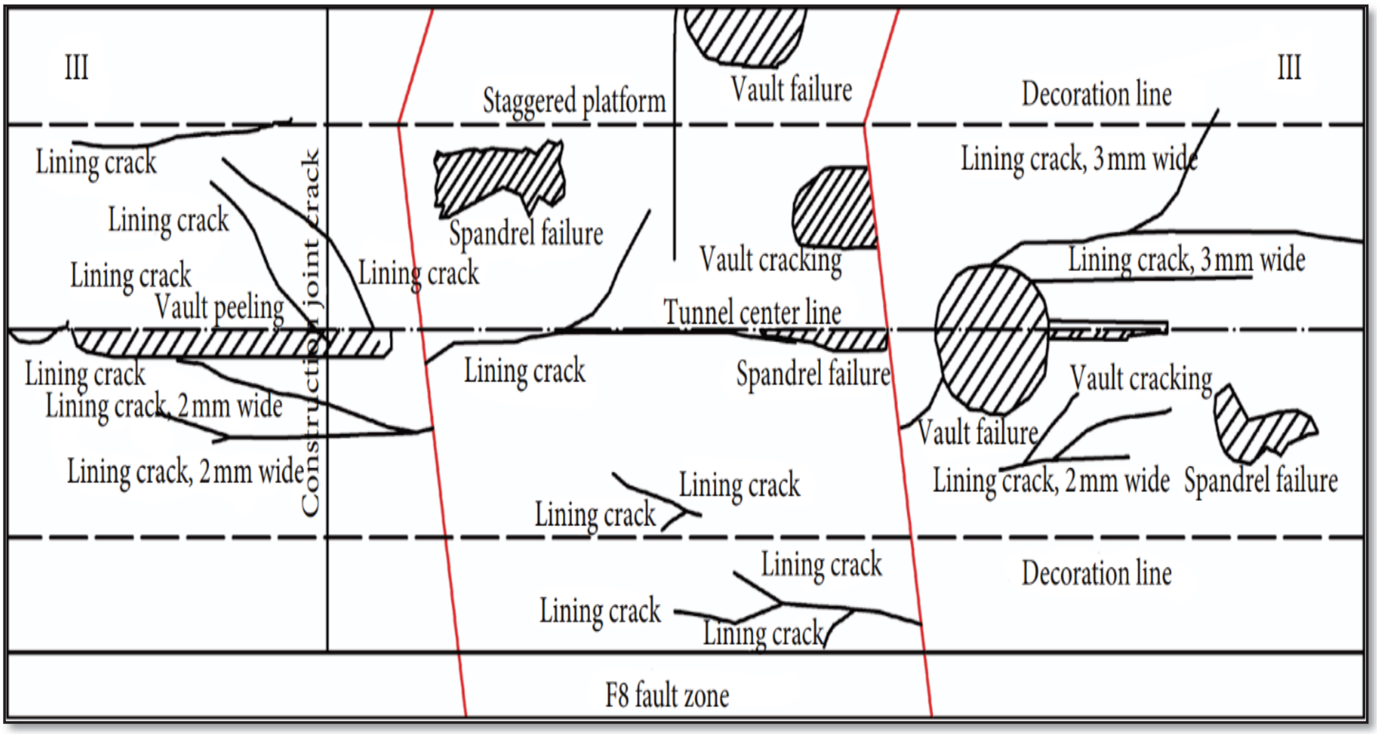

Figure (1.1): Seismic damage of Longxi Tunnel. (a) Lining collapse. (b) Lining dislocation. (c) Damage near the fault zone.

1.2The Problem Statement of Study

Regarding to the damages that happen because of the tunnels that were constructed in the soils which are susceptible to earthquake-induced vibration in seismically active areas and because the depth of the tunnel is usually shallow and located within the soft ground area, a complete understanding of tunnel behavior is needed. A wide range of case histories and the different techniques used in tunnel seismic analysis are reviewed in this study. The seismic impacts on tunnels and the factors affecting damage to tunnels due to earthquakes are summarized in this study. Besides, the effect of various factors on the seismic behavior of tunnels in soils was studied in this study.

FEM has become a popular tool that can simulate the tunnels and the effect of earthquake simulation to predict the strength of deformations and the distribution of stresses using a numerical method.

1.3 The Aims of the Study

The aim of this study is oriented in detecting with the following:

1. Estimate the changes that happen to the soil body and the tunnel in terms of stresses, strains, and displacements.
2. Determining zones of failure and plastic flow in soil.
3. Locating zones of safety.
4. The intensity of the proposed earthquake is varied, and the effects are monitored.

1.4 Methodology

1. Collect data from soil reports in Iraq (and much preferable in Diyala**).**
2. Using the PLAXIS program (Version 20) to calculate the in-situ soil stress, strains, and displacement.
3. A proposed tunnel is constructed in specified dimensions and depth. And again, stresses, strains, and displacements are calculated in the body of soil around the tunnel and a little far away.
4. A Kalamata and Kocaeli earthquake is simulated in a program and perfected on a tunnel and body of soil surrounding it.

1.5 Thesis Layout

The aim of this thesis consists of five chapters.

Chapter one provides a general introduction and information about tunnels, earthquakes and their effect on tunnels, and the scope of the study.

Chapter two covers a brief review of the available literature of the various tunnels and earthquakes. This chapter also provides a review of previous studies that dealt with the impact of the tunnel and earthquakes on the adjacent soil during tunnel construction and earthquakes and a review of methods for predicting the behavior of stresses and soil stability.

Chapter three presents the numerical modeling methodology for constructing tunnels and earthquakes and the construction model procedures.

This chapter also explains field and laboratory investigation data for a limited area.

Chapter Four includes a presentation and discussion of test results of finite elements, while Chapter Five presents a summary of the main conclusions and recommendations of future work.

ABSTRACT

With the increasing population of major cities around the world, the development of underground urban infrastructure has become a major focus. If these underground structures are constructed in earthquake areas, then their dynamic response to seismic loads must be determined to minimize economic damage and threats to human safety. Therefore, an attempt has been made to study the settlement and behavior of stresses for the tunnel and the surrounding soil through the tunnel simulation and imposing the earthquake.

This research study is carried out to predict the behavior of the stresses and ground movement effect of applying earthquake on the soil and the tunnel. A numerical model is built and developed for a tunnel project within the governorate of Diyala. For this purpose, one profile of soil investigations is brought from Almafraq overhead intersection project which locates in the Diyala government and two earthquakes are imposed which consist of Kalamata and Kocaeli earthquakes.

The main objective of this research is to study the behavior of stresses and determine the settlement and plastic zone in the area of study using a finite element method to assess and the determination of extent the impact on the soil. The model is run as three-dimensional in both undrained clay soil in three layers and drained to sandy soil in one layer of states with the applied Mohr-Coulomb model by the PLAXIS 3D (Version 20) program.

Results are presented in terms of stress-depth curves. Those stresses are the vertical and horizontal, total and effective in addition to the pore water pressure. The changes in the state of stresses compared to the in-site soil are put into consideration. Three vertical sections are chosen to study the earthquake effects on the surrounding soil. The first section (x=0) runs through the center of the tunnel. The second section is located near the lateral edge of the tunnel, while the third section is chosen more or less far from the tunnel edge. It is believed that the mentioned details of the analysis will provide the full vision of stress change in the soil profile. The deflected shape of the tunnel is shown as well. Through running an axisymmetric FE analysis, calculation results revealed mat large changes in stresses take place in zones of soil near the tunnel boundaries. In other words, the close-nearby soil is mostly affected by tunneling. These stress changes reduce as proceeded farther away from the tunnel horizontally and seam to reach negligible values for distances above 15m away tunnel edge in the phase of the tunnel, so it was observed that the most probable safe distance (2D) from the tunnel, which D represents the diameter of the tunnel. While at the earthquake phase, the upper zone of the tunnel considers safer at 58% because it is far from the influence of the earthquake and its soil is clay, while the critical zone locates in contact with the tunnel. Furthermore, it was noted that the amount of settlement of the soil is so little in the phase of the tunnel compared to the dynamic rate of 86%.